

SIESMIC SENSITIVE MASS MOTION POWER CONVERTER FOR PROTECTING  
STRUCTURES FROM EARTHQUAKES

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**[0001]** This application claims priority for all purposes to pending U.S. application ser. no. 60/431914, filed 12/09/2002, by the same inventor.

**FIELD OF THE INVENTION**

**[0002]** The invention relates to devices for the protection of structures from seismic activity, and more particularly, to a seismic sensitive inertial mass motion power converter for converting seismic power to desirable structural responses during seismic activity.

**BACKGROUND**

**[0003]** Structures such as buildings and bridges when subjected to an earthquake may be subjected to lateral and vertical oscillating motion or movement of their foundation structures and supports in the order of plus or minus a foot or more relative to an inertial reference. The frequency of the oscillatory motion is typically in the order of about 1/2 hertz. This motion imposes severe lateral and sometimes vertical inertial forces that may exceed the design load limits of the structure. Deformation or failure may occur at one or more support points and/or within the internal structure, causing damage or destruction to the structure.

**[0004]** Seismic shock waves tend to radiate outward in all directions from the epicenter of an earthquake. Structures directly above the epicenter are more likely to incur vertical inertial shocks, and structures further removed from the epicenter are more likely to incur mainly horizontal shocks. A particular structure may experience an earthquake with shock components measurable in all three axis; X, Y, and Z (vertical). There is a host of readily

available reference material on the general subject to which interested readers may avail themselves.

**[0005]** Seismic induced horizontal or lateral inertial forces are for illustration somewhat analogous in effect to a series of very high wind gusts oscillating in direction. The building in such a condition would be subjected to two types of stress; bending and shear. There would be a pattern of sharp, repetitive bending moments applied over the vertical distance or height of its wind resisting profile, resisted by its exterior shape, weight or mass, interior structure, and finally its attachment to its foundation support points. There would also be an alternating shear stress occurring at the foundation support points, the wind in effect trying to push the building or structure off its foundation first in one direction and then the other.

**[0006]** In the seismic case, the bending moment due to lateral seismic activity is directly resisted by all of the same components except the exterior shape. The effect is resisted by the building mass over its vertical distribution or height, the interior structure, and finally its attachment to its foundation support points. The shear stress again acts to push or slide the structure off its foundation first in one direction and then the other.

**[0007]** The stress of a sharp pattern of oscillating bending moments can cause a building structure to deform laterally. Even small deformations may leave the structure unreliable with respect to further stress, rendering the building unsafe and unusable until repaired. Alternately or in combination, the shear stress can cause a structural failure to occur at one or more foundation support points, sometimes causing a partial or total collapse of the structure.

**[0008]** Vertical loading problems are less affected by wind than by seismic or other perturbations to the supporting foundation or its earthly support. However, most structures are relatively resistance to vertical shocks, as the support system is generally uniformly distributed beneath the structure, and the columns of the internal skeleton are vertically aligned with the support points, providing a mainly vertically compressive load. Vertical

oscillations of buildings and other structures occur in earthquakes, but these do not cause much damage for most structures. An exception to this was the recent 2001 earthquake in Washington State, where the Seismic Disturbance was very deep and the vertical oscillations caused most of the damage.

[0009] With respect to engineering considerations for adding structural tolerance for seismic events, there are two general cases: the base-isolated structure intended to remain inertially stationary during seismic events; and the non-isolated structure which needs sufficient strength, flexibility and dampening to withstand a seismic event. In the base-isolated case; it is desirable to stabilize the structure inertially so that it is isolated at its support points from seismic ground motion and is able to remain inertially at rest. For other non-isolated structures, it may be more useful to try to couple and coordinate the motion of the structure to and with its support points for structural compliance or response to ground tremors during seismic activity.

[0010] What is needed, therefore, are systems and techniques for isolating structures from seismic motion, protecting structures from internal deformation due to seismic events, reducing shear forces between layers or components of structures, and coordinating uniform and compliant structural movement with the seismic motion occurring in the proximity of its foundation supports.

[0011] The need for seismic protection, either by improved base isolation or more compliant structural response, is applicable to all type of structures including nuclear power plants, hospitals, commercial and residential buildings, towers, and bridges.

## SUMMARY OF THE INVENTION

[0012] At the heart of the invention there is a power converter in which the seismic power released in an earthquake is converted to useful work by use of an inertially free floating mass confined in an earth bound cage, with a range of available mass motion in the cage being in excess of the magnitude of a seismic motion of interest, where the response of the

inertially free floating mass to the seismically induced movement of the cage around it is applied as a stabilizing force in any of numerous ways which may be otherwise passive, to protect a structure from damage due to the seismic activity.

**[0013]** Goals of the invention include the introduction of systems and techniques incorporating a subterranean seismic actuated power converter for powering improved inertial stability systems for structures with base isolated support systems, for powering counter mass motion systems within structures for protecting the structures from internal deformation due to seismic events, and for reducing shear forces and coordinating uniform movement of a structure with its foundation or earthly supports during the occurrence of seismic activity in the proximity of the structure.

**[0014]** It is among the objects of the invention to provide devices, techniques and systems for harnessing the energy released in a seismic event, so that it can be used to control or power a stabilizing mechanism for base-isolated or inertially protected structures, or used to control or power inertia-opposing, mass motion devices incorporated into a structure to induce a shift in the structural mass concurrent with the seismic shift in position of the foundation.

**[0015]** To these ends, there is described a seismic sensitive, inertial mass motion power converter which may have a single or multi-axis seismic motion sensitivity and output. The seismic actuated power converter is impervious to wind or other influences, being reactive only to components of seismic activity occurring in its own axis of orientation in the immediate proximity. The output of the seismic power unit may be used as a control input to an active or semi-active seismic protection system, or as a power source for a passive or semi-active system, where the occurrence of the seismic activity supplies power to and controls the application of the converter's available mass motion to the system.

**[0016]** Such a seismic sensitive inertial mass motion power converter may incorporate a substantial, inertially free floating mass in the form of a piston, arranged substantially at the center point of a hydraulic cylinder so as to divide the cylinder into two hydraulic

reservoirs. The piston may or may not be mounted on a shaft within the cylinder but is in any case configured for very low frictional drag resistance to sliding motion within the cylinder. Each end of the cylinder communicates its respective hydraulic fluid reservoir to servomechanism or slave devices as is further described below.

**[0017]** It will be appreciated that the two opposing reservoirs of the cylinder are inversely proportional in volume. The proportionality of the reservoir volumes may in some cases be unitary, i.e. 1 to 1, but variations of piston and cylinder diameters between the two ends of the cylinder offers flexibility to the system designer as to the output characteristics of the unit, and other than 1 to 1 ratios are within the scope of the invention.

**[0018]** Other configurations of a seismic actuated power converter are within the scope of the invention. For example there may be a subterranean chamber within which is movably supported a mass that is centered as a home or reference position and tethered on opposing sides in two or three axis. The tether cables are routed to a two-axis or three axis seismic protection system as two-way tension outputs in each respective axis of the seismic sensitive power converter. Stated more simply, the device is a seismic sensitive, cable based, two or three axis, inertial mass motion power converter. Other examples of a subterranean seismic actuated power converter used to power and control associated seismic protection systems are within the scope of the invention will be apparent to those skilled in the art from the description and figures that follow.

**[0019]** In a single axis hydraulic power converter example, a seismic power converter master cylinder, being buried firmly within the earth proximate the protected structure, is necessarily subject to any seismic activity that occurs in the area. The orientation of the cylinder defines its axis of sensitivity and response. A low leak rate, equalizing circuit between the two reservoirs or ends of the cylinder in cooperation with centering bias springs, may be used to provide means for permitting the piston to slowly recover to a desired "home" position after a displacing occurrence. Bias springs may be sized for resisting external forces such as wind forces on the structure that are being fed back through the linkage of the seismic protection system.

[0020] Where buildings or other structures are erected or constructed on inertially protective support structures to be isolated base systems such as a damped sway foundation system as disclosed in DAMPING DEVICES FOR EARTHQUAKE PROTECTION OF RESIDENTIAL STRUCTURES, copyright 1995 by Randolph Langenbach, the seismic power units of the invention may be used to power a set of servo'd hydraulic slave cylinders oriented at right angles in the horizontal plane to enhance the intended inertial stability of the structure. For example, one seismic sensitive power unit oriented for X axis motion may power multiple servo units of the same orientation, one servo unit for each vertical support column; or there may be one power converter unit for each servo unit, or multiple power converters affecting one slave unit. A similar set of power converters and slave units would serve the Y axis. Used in this manner the invention provides a positive force in each horizontal axis, using seismic power according to the invention to help overcome the resistance to inertial stability and relative lateral movement that is inevitably present in a purely passive inertial protection system, due to the various perimeter structure, utility and access connections to the ground, as well as any resistance to lateral movement of the structure on its foundation supports.

[0021] Where a building or other structure is on a conventional foundation or slab or as for a bridge on bridge end supports for which there is no provision for base isolation during earthquakes, there may be shear stress at the foundation or between other layers or components of the structure, or internal deformation of the structure due to bending moments on the structure. Here the invention may be employed for a different purpose. Servo'd counter-inertia mass motion devices may be incorporated at strategic locations within the structure to provide additional mass and a capability for shifting the counter-inertia mass in one direction, while providing a reactive force on the remaining mass that is the structure, tending to propel the structure in the direction of the seismic motion in concert with the slab or other foundation supports while preserving the inertial status quo for the total mass. The servo'd counter mass motion devices must be strategically distributed vertically within the building, or distributed over the length of a bridge for example, according to the limits of the internal structure to absorb the forces and move the structure in a coherent manner so as to reduce and not contribute to excessive deformation.

It is the harnessing of seismic power through the use of subterranean seismic sensitive inertial mass motion power converters in accordance with the invention that makes this more practical than otherwise.

[0022] It is a goal of the invention to provide a seismic sensitive inertial mass motion system for protecting an earthborn structure from seismic activity, where the seismic power converter consists of a chamber suitable for permanent earth bound placement on the surface or under it, close to a base component of the structure. There is a mass suspended loosely in the chamber for maximum freedom of relative movement in selected directions. The chamber is configured with an available range of motion for displacement of the mass in the selected directions. There is a servomechanism or slave displacement unit associated with the structure and oriented for operation in the same selected directions as provided for the mass motion. Finally, there is a transfer mechanism, be it electrical, hydraulic, mechanical links, gears or cables, for translating the displacement of the mass to the servo displacement unit.

[0023] It is another goal of the invention to provide such a system with at least one seismic power converter securely earthbound with a selected axis and angle, close to one of the support members of a base isolated structure. It consists of a hydraulic master cylinder and piston mechanism, filled with hydraulic fluid and configured with an available range of motion for inertial displacement of the massive piston equal to at least the range of earth motion during a typical earthquake. The cylinder has a piston home position at the midpoint of its range of motion. There is in addition at least one hydraulic servo cylinder associated with the structure and oriented in the same said axis and angle as the master cylinder. There are hydraulic lines for translating the displacement of the piston to the hydraulic servo cylinder. The servo displacement unit is firmly attached to the ground at one end, and to the support component of the structure at the other end. Hydraulic lines are arranged to link the power converter and servomechanism so that displacement of the piston during seismic activity occurs in phase with the relative movement of the support component and the structure to the earth. In other words, the inertial position of the piston

and the support component remain the same with respect to the axis of the power converter.

[0024] It is yet another goal to provide a seismic sensitive inertial mass motion system for protecting an earthborn structure from seismic activity, consisting of at least one seismic power converter securely earthbound with a selected axis and angle proximate a base support component of a non-isolated structure. There is at least one hydraulic servo mechanism or slave cylinder linking a counter mass to the structure and oriented in the same axis and angle as its respective master cylinder. There are hydraulic lines for translating displacement of the power converter piston to the hydraulic servo cylinder. But the hydraulic servo cylinder in this case translates displacement of the power converter piston within its cylinder to movement of the counter mass with respect to the structure so that an in-axis movement of the master cylinder results in an opposing movement of the counter mass relative to earth or cylinder motion.

[0025] The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and not to limit the scope of the inventive subject matter.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Fig. 1 is a cross sectional elevation view illustrating a seismic actuator for earthquake protection of structures.

[0027] Fig. 2 is a cross sectional elevation view illustrating a seismic isolation system for earthquake protection of structures.

[0028] Fig. 3 is a diagrammatic view of a three axis pylon isolation system with seismic power converters and servo'd stabilization subsystems operating in the X and Y axis.

[0029] Fig. 4 is a diagrammatic top view of a single span bridge and two bridge supports, the bridge being configured with X and Y axis counter mass motion systems at each end powered by seismic sensitive inertial mass motion power converters of the invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0030] The invention is susceptible of many embodiments. What follows is merely a description of preferred embodiments, illustrative but not exhaustive of the scope of the invention. Referring to Fig. 1, there is illustrated a first embodiment of the invention in a cross sectional elevation view of a subterranean, seismic sensitive, mass motion power converter 1, for use in protecting structures from seismic activity. The device is a power and control source for systems intended for earthquake protection of buildings, towers, bridges and other structures that depend for support on an earthborn foundation system.

[0031] Still referring to Fig. 1, the seismic power converter 1 includes a hydraulic master cylinder 10, configured with optional external flanges 20 for extended engagement with the earth in which the device is buried. Within master cylinder 10 there is disposed an inertial mass piston 12, slidably mounted on axial shaft 13 which extends from one cylinder end to the other. Piston 12 divides the interior of cylinder 10 into two fluid reservoirs, 18 and 19, the volumes of which vary inversely with movement of piston 12.

Piston 12 may be lightly biased in some manner so that it is normally in the center of the cylinder before an earthquake, but otherwise has very low frictional resistance to sliding motion within the cylinder. In one embodiment, the centering bias is applied by a pair of opposing center springs 16. The master cylinder and associated hydraulic systems are preferable entirely filled with a substantially incompressible hydraulic fluid.

**[0032]** The power converter in its entirety, when secured to or within the earth near a support structure, is a motion sensitive, inertial mass, configured by its confinement within the cylinder to harness the power generated by the seismic activity to the extent of the mass of the piston and the available range of axial displacement of the cylinder from its inertial reference point, back and forth around the inertially stationary piston. The unit is able to transmit this power via hydraulic fluid lines 14 to servo'd actuators or slave cylinders incorporated into the protected structure or its supports or between the structure and the ground in various schemes for providing seismically coordinated extension or retraction between selected stress points. The seismic power converter, once installed, is insensitive to all but seismic activity, and then only to the extent occurring in its axial orientation.

#### Stabilizing A Base Isolated Structure With Seismic Power

**[0033]** One embodiment of the invention is used to convert power from an earthquake to provide inertial stabilization to structures mounted on isolated base support systems that are intended to permit a limited range of lateral displacement between the structure and its support.

**[0034]** Referring now to Fig. 2, there is illustrated a single axis depiction of one embodiment of an inertial stabilization augmentation system for structure 22, mounted on lengthy sway supports 26 for base isolation from earthquakes. This embodiment of the invention is also applicable to other base isolation systems and designs. Notwithstanding the sway foundation design, the inertial stability of structure 22 may be confounded by numerous utility pipes, wires and connections between the structure and ground, not shown in this view, as well as dampers intended to resist wind forces, and peripheral structure-to-

ground appendages such as steps, access ramps and wall skirts. These numerous non-supporting connections collectively resist the lateral displacement of structure 22 intended to occur during an earthquake for inertial stability. There may be as well significant static and kinetic friction inherent in some types of horizontal base isolation systems. The net result is that the promised inertial isolation of the structure is significantly compromised.

**[0035]** In this embodiment, the seismic power converter 1 of Fig. 1 is buried in the earth beneath structure 22. The flexible hydraulic lines 14 are connected to a hydraulic slave cylinder 24, mounted substantially horizontally between a ground anchor 23 and the base of structure 22, so that a change in the shaft length extension of slave cylinder 24 causes a lateral shift in the position of structure 22 with respect to the ground. The seismic power unit 1 and hydraulic slave cylinder 24 are configured to provide a 1 to 1 ratio of servo unit shaft extension to motion of piston 12 in cylinder 10; such that the relative motion of the structure and the piston are necessarily in the same direction and of the same distance, with the available force in the power converter being applied to overcome resistance to the inertial stability of structure 22.

**[0036]** As will be readily appreciated by those skilled in the art, when the ground moves laterally a given amount with respect to an inertial reference, cylinder 10 will tend to move the same distance with respect to piston 12. The structure, of course, would remain inertially stationary except for the drag of its various ground connections. However, in accordance with the invention, the seismic force captured in cylinder 10 is transmitted hydraulically to servo 24, applying the full available force to help overcome any resistance to a like amount of displacement between the ground and the structure. This same configuration can be repeated at all points where the building is supported, and in both X and Y axis in the horizontal plane. The application of this additional force of stabilization helps to overcome the resistance in the base isolation system, resulting in less trauma to the structure.

**[0037]** Summarizing the contribution of the invention, since in theory neither the power unit piston nor the structure is moving and the servo unit is tied to the same inertial

reference as the power unit cylinder, the ground, no force is exerted on the structure and no work is done, *per se*. However, there is resistance to lateral displacement inherent in any base isolation system, and in the wind resistance components and auxiliary connections between the structure and the ground, that must be overcome in order for the structure to remain inertially stationary. Practically speaking, the inertial mass in the seismic power converter must be large enough to capture sufficient seismic energy to overcome these resistances, (of course in an active system with suitable controls, additional energy may be available). The hydraulic lines and servo units must be suitably sized to quickly transfer the energy to the servo'd devices in or at the base of the structure.

**[0038]** Referring now to Fig. 3, there is illustrated a three axis embodiment of a stabilization system for one pylon of a multi-pylon, base isolated, four to six million pound structure. The representative pylon 30, intended to support 200,000 pounds of the structure and configured at joint 32 to allow lateral displacement of the upper end, is also supported by the five foot diameter piston 34 of a vertically oriented hydraulic fluid cylinder 36 for vertical seismic motion protection. An active subsystem pad height monitor and supplemental 300 psi (pounds per square inch) source 38 of hydraulic fluid maintains the pylon at the correct inertial reference level.

**[0039]** The seismic power converters 1 of the invention are provided in the form of two stainless steel cylinders 10, 36 or 48 inches in length and 36 inches in diameter, buried in the ground near the pylon and oriented for piston motion in their respective X and Y horizontal axis. A piston 12 in each of the cylinders is preferably fabricated of depleted uranium for its high density although other materials may be used. At 12 to 24 inches in length and 36 inches in diameter, pistons 12 have a mass or weight of about 8000 or 16000 pounds. The pistons have a range of motion of about plus and minus 12 inches from their center point or home position with in the cylinder, for reaction to seismic activity.

**[0040]** The seismic force captured within the cylinders by the relative motion of the pistons is applied hydraulically to overcome resistance to the concurrent relative lateral displacement of the structure during an earthquake, such as is caused by utility connections

51 and entrance structure 52. Servo'd stabilization slave cylinders are of the same diameter as cylinders 10, providing a 1 to 1 correspondence of piston 12 mass motion range to respective slave cylinder extension or retraction in response. Slave cylinders 42 and 44 are respectively ground bound at one end and linked to pylon 30 at respective flex joints 43 and 45. The energy collected from the relative mass motion of the 8000 or 16000 pound mass motion piston 12 within cylinders 10 is applied via the hydraulic lines to the respective slave cylinders and hence to the structure to overcome any resistance to the desired relative displacement of the structure to the ground.

**[0041]** This system is fundamentally different from the current art of damping the structure or isolating the structure by isolating shock mounts. Ideally, a 3-axis stabilization system modified as described to use the seismic power converter and slave unit as described would allow the structure to remain perfectly still. In practice, this is difficult to achieve. It is expected that the stabilization augmentation system of the invention, using only the power generated by the earthquake, may reduce the motion of the structure by up to ten times or more, over base isolation systems not similarly equipped.

**[0042]** It is also common knowledge that the use of base isolation systems extends to the Z axis or vertical domain, for protection against earthquakes producing a lot of vertical motion as in the recent earthquake in 2001 around the Seattle area in the state of Washington. A vertical stabilization system typically requires or presupposes an isolated or floating support structure capable of motion over a limited vertical distance when vertical seismic forces occur. The Fig. 2 embodiment horizontal stabilizing technique is similarly applicable to the vertical case by use of a vertically oriented power converter and slave cylinder circuit, where the slave cylinder is properly earth bound at one end and coupled at the other end to the vertical support member.

**[0043]** Furthermore, the power converter of the invention in which seismic power is converted by use of an inertially free floating mass confined within an earth bound cage and provided with a suitable range of motion, may be used in these and alternative ways to power and/or control active or passive, single or multiple axis seismic protective systems

for structures, or other on or off-axis or alternate axis systems subsystems, devices or components requiring a seismically actuated inertial type power source, whether for positive or negative oriented inputs from the power converter.

**[0044]** The embodiments described above are passive in that there is no requirement to supply significant additional power to the system. It should be noted that there may be useful variations for 2nd order, longer term, low level power or control inputs for maintaining system alignment and/or balance, such as for keeping pistons centered and hydraulic systems pressurized or in augmenting the power applied or controlling a constantly available active power source in a given situation.

#### Augmenting Structural Mass With Seismic Powered Counter Motion Mass

**[0045]** Referring now to Fig. 4, there is another embodiment of the invention, again utilizing the seismic sensitive inertial mass motion device of Fig. 1, but here used to power a counter mass motion system within a structure that assists structural motion to move in the direction of ground motion. As is known in the art, by driving an associated mass within the structure in a direction *opposite* to ground motion, there is created an equal and opposite reaction to the structure to move in concert *with* the ground motion, while tending to maintain the total mass at closer to its inertial reference point. By using the power captured by the seismic power unit of the invention, the requirement for an active power source can be reduced or eliminated. It should be clearly noted that this embodiment and method of application is not applicable to structures or buildings configured with base isolation systems, but is rather for structures and buildings which by default or design are better suited to being configured for accommodating or being compliant with the earth tremors, rather than being isolated from them, such as buildings on slab foundations and bridges on solid supports.

**[0046]** While as indicated, this aspect of the invention can be applied in vertical structures such as buildings as well, it is here illustrated in a horizontal structural span. The Fig. 4 diagrammatic illustration is of a single span bridge 60 supported at each end by a rigid

bridge support 62. A pair of counter mass motion hydraulic slave units 64 are embedded within each end of the bridge structure, one transverse to the span and one aligned with the span. Each mass motion slave unit has a respective mass 68, and is associated with a seismic power converter 1 as in Fig. 1, buried in the ground near the bridge support with the same orientation.

[0047] Hydraulic lines 14 are connected between the ends of the associated cylinders such that during an earthquake, the counter balancing masses 68 controlled by their respective counter mass motion slave units 64 are driven by relative motion of the pistons in power converters 1 in the opposite direction. This movement of the counter mass 68 in the opposite direction thus urges bridge 60 to move in the same direction as its bridge supports 62. This benefit can be accomplished with a totally passive system, using only the power generated by the seismic activity itself. Additional power may be added by an active power source to accelerate the movement of the counter weights so that their effect is amplified, but this makes the system more complex and more vulnerable.

[0048] As will be readily appreciated by those skilled in the art, the size and placement of counter masses 68 within a vertical or horizontal structure will require calculated distribution throughout the structure to balance the movable mass to the structure's internal mass and skeletal support, with special attention to devoted to providing suitable support points for both ends of slave units 64 where counter mass motion is opposed by the structure. Vertical distribution of the counter mass motion devices within a building not equipped with base isolation may be as frequent as every story, including roof or attic layers. Smaller counter mass motion devices can be strategically placed where needed.

[0049] Application of this embodiment to tall structures should not be confused with use of a vertically oriented counter mass motion device or implementation. Although vertical implementation of this embodiment is possible, it is not viewed as practical in structures of any significant weight, due to gravitational alignment with vertical seismic motion.

[0050] It should be noted that while the theory of the counter mass motion embodiment is to protect the structure from catastrophic deformation or dislocation from its base by encouraging a corresponding response by the structure to the earth's movement, contents not protected from the resulting motion, such as furniture, pictures, chimneys and possibly occupants, may suffer collateral damage.

[0051] While the embodiments described rely mainly on converting seismic power for functionality, it is within the scope of the invention to incorporate the seismic sensitive inertial mass motion device of the invention into other passive, active, and semi-active stabilization systems for protecting all types of earthborn structures from seismic activity or wind loads. For example, the seismic sensitive device can be used to discriminate between wind and seismic forces affecting a building or structure, in order to actuate different or additional responses. The passive protective systems described may be configured with an active power source that is energized under certain conditions to provide additional stabilizing or counter mass motion capability.

[0052] One skilled in the art would readily appreciate that the use of damper cylinders or shock absorbers incorporated into structures to limit deformation due to wind and earth tremors, as are well known in the art, could also be used in conjunction with the above systems.

[0053] Another example of the invention is a seismic sensitive inertial mass motion system for protecting an earthborn structure from seismic activity, consisting of a seismic power converter in the form of a chamber suitable for permanent surface or subterranean placement proximate a base component of the structure, within which is contained a substantial solid inertial mass. The chamber is configured with an available range of motion for inertial displacement of the mass inside the chamber, in at least one axis.

[0054] There is a servomechanism associated with the structure, capable of a mechanical reaction, preferably a linear extension and retraction capability, but rotation or other mechanical responses are within the scope of the invention. The response of the servo

displacement unit reflects a displacement of the inertial mass in the chamber. The servo unit is oriented for operation in the same axis as the chamber, so that the displacement essentially duplicates the relative motion of the inertial mass in the chamber. The servo unit is connected to the chamber by a fluid, mechanical, electrical or other means for translating the displacement of the inertial mass to the servo displacement unit.

**[0055]** There may be two or three sets of power converter and respective servo displacement units associated with the structure or with a support component of the structure. The various sets may be oriented at right angles to each other.

**[0056]** The means of translating the displacement of the inertial mass to the servomechanism, and the nature of the servomechanism itself, may be or include motors, gears, torque tubes, hydraulic lines and actuators, push/pull rods or cables or some combination. The chamber may be a hydraulic cylinder filled with hydraulic fluid, and the inertial mass be a piston having a home position at a midpoint within the cylinder. The means for translating displacement may be hydraulic lines, and the servo displacement unit may be a hydraulic slave cylinder.

**[0057]** The seismic sensitive inertial mass motion system may be associated with at least one base isolated support component of a base isolated structure. The servo displacement unit may link the ground to the support component, and the means for translating displacement of the inertial mass to the servo unit may be an inertially in phase linkage of the mass to the support component so that the inertial in-axis position, or displacement of the mass and the support component with respect to the ground, are the same.

**[0058]** The seismic sensitive inertial mass motion system may be associated with a non-isolated structure, where the servo displacement unit connects a movable counter mass to the structure so that any force applied to the counter mass creates an equal and opposite force on the structure. The means for translating displacement of the inertial mass to the counter mass may be a linkage whereby an in-axis movement of the chamber and relative displacement of the inertial mass results in a movement of the counter mass in the opposite

direction as the chamber and ground. A non-isolated structure may be but is not limited to a building, or a bridge supported on bridge supports.

[0059] The servomechanism in the non-isolated case may be a hydraulic servo cylinder linking the movable counter mass to the structure, and may be a two ended servo cylinder and movable counter mass assembly of fixed length, the two ends of which are secured to two respective attach points in the structure, where the counter mass is movable by displacement of the inertial mass and resulting actuation of the servo cylinder, along the length of the assembly substantially on a line between the two attach points. The force acting on the counter mass is, of course reflected in an equal and opposite force acting on the structure through the two attach points.

[0060] The foregoing description of the embodiments of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of this disclosure. It is intended that the scope of the invention be limited not by this detailed description, nor by the exemplary claims appended hereto.